Material Testing Techniques For Existing Masonry

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International Symposium
Seismic Retrofit of Unreinforced Masonry
Heritage Churches in the Philippines
National Museum of the Philippines
January 13 - 14, 2016

Atkinson-Noland & Associates, Inc. New York | Boulder
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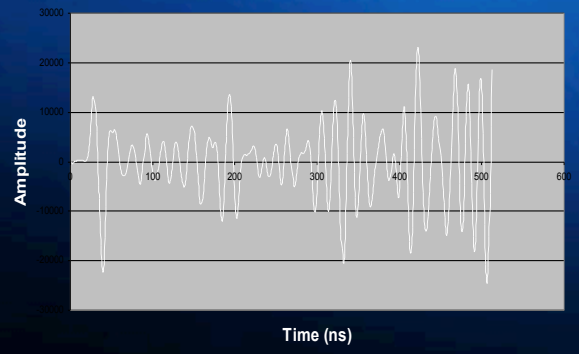
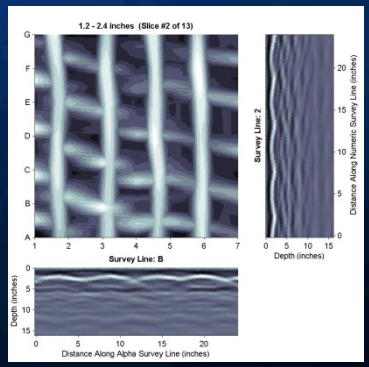
Nondestructive Evaluation
In Situ Tests
Laboratory Testing

- Typical applications
- Planning (or specifying) an investigation
  - Interpreting and using data
  - Validation and proof testing



INTERPRETATION

- Experience
- Software
- Complementary methods
- Calibration
- Probe



What information do you need?

- As-built conditions
  - Geometry
  - Connections
- Current condition
  - Deterioration, corrosion
  - Distress, cracking, delamination
- Engineering properties
  - Strength
  - Stiffness

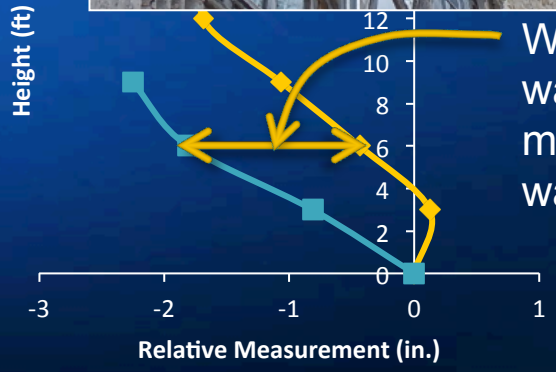
Nondestructive Evaluation (NDE)

- Visual
- Surface hardness
- Metal location
- Pulse velocity
- Impact-echo
- Tomographic imaging
- Sounding
- Microwave radar
- Infrared thermography
- X-ray
- Borescope

Visual Evaluation: Condition Survey

- Historical Information
  - Review drawings
  - Research history
  - Interviews
- Visual
  - Measurements
  - Plumb, level
  - Photographs

Photo by Zach Rice



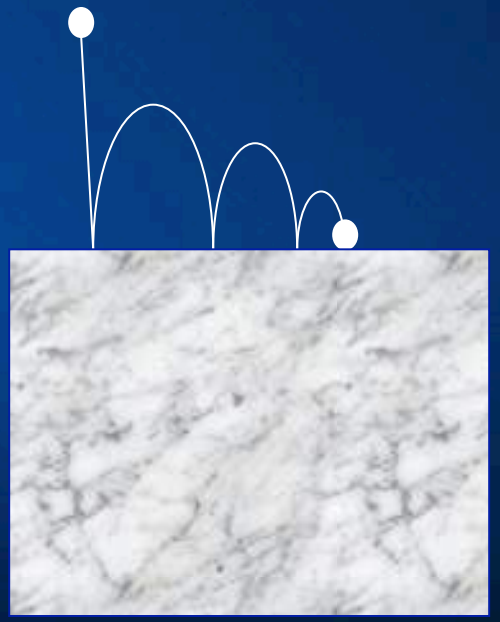
Why is the outside wall face deflecting more than the inside wall face?

Rebound Hardness

Rebound of an elastic mass depends on the hardness of the surface upon which it impinges

Ernst Schmidt, 1948

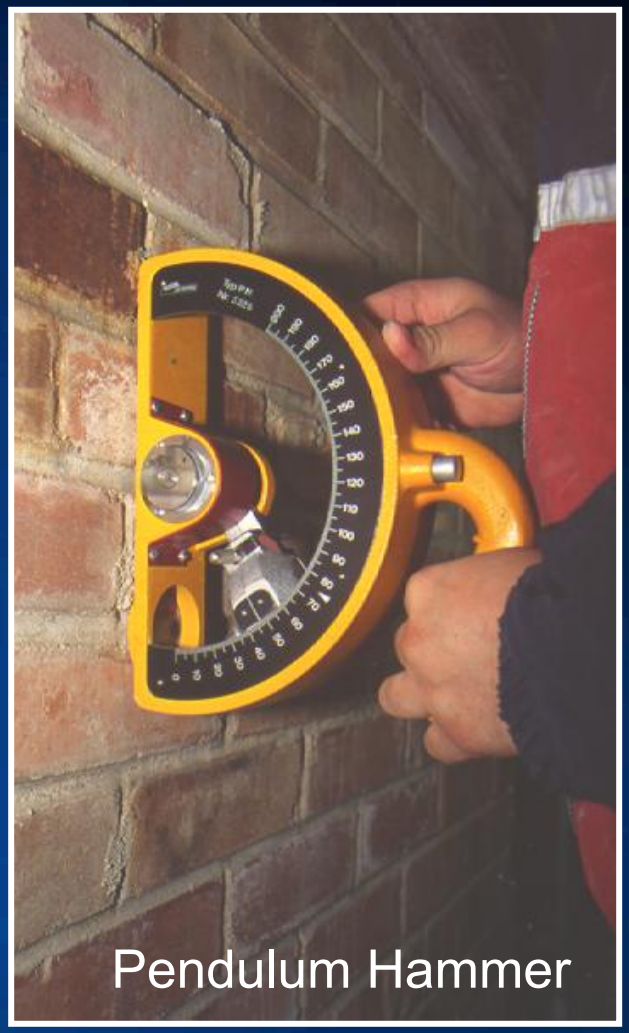
"Schmidt Hammer"



Rebound Hardness

Uses:

- Material uniformity
- Deteriorated or poor quality zones
- Characteristic changes over time
- Compressive strength?
  - ➔ ASTM C805-75: "*This method is not intended as an alternative for strength determination*"

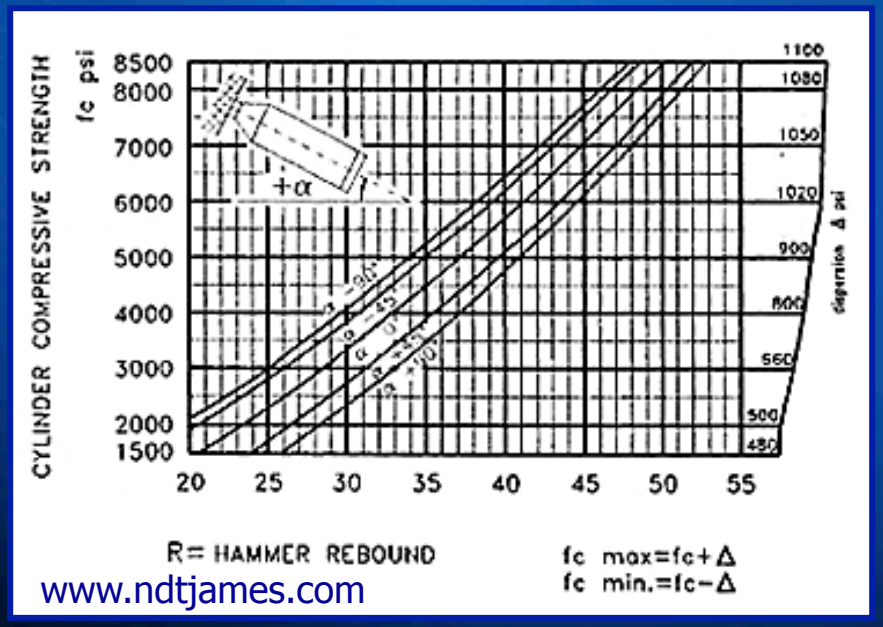


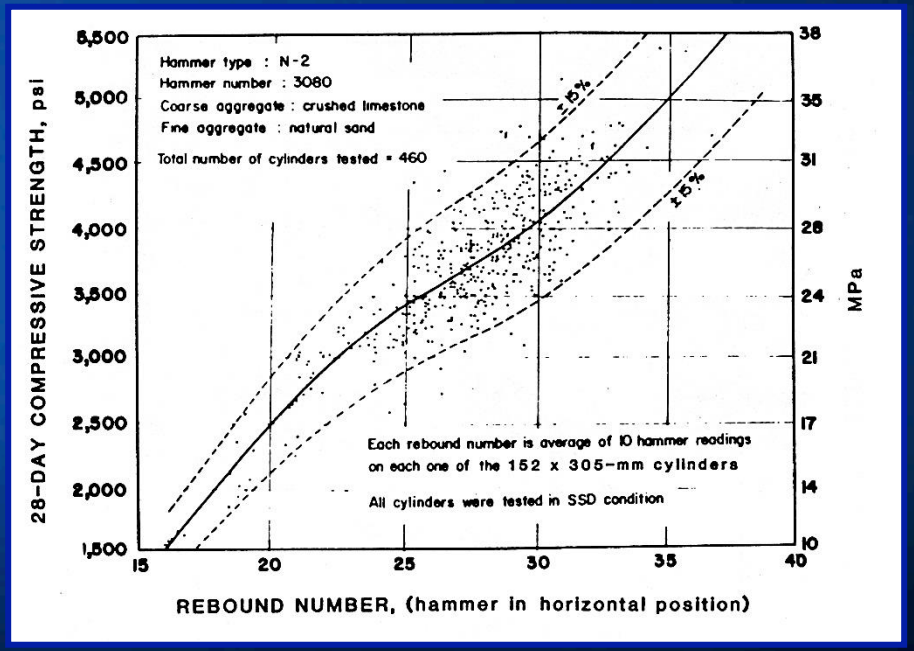
Pendulum Hammer

Rebound Hardness

Relating rebound number to strength

- ±15% (lab)
- ±25% (realistic)

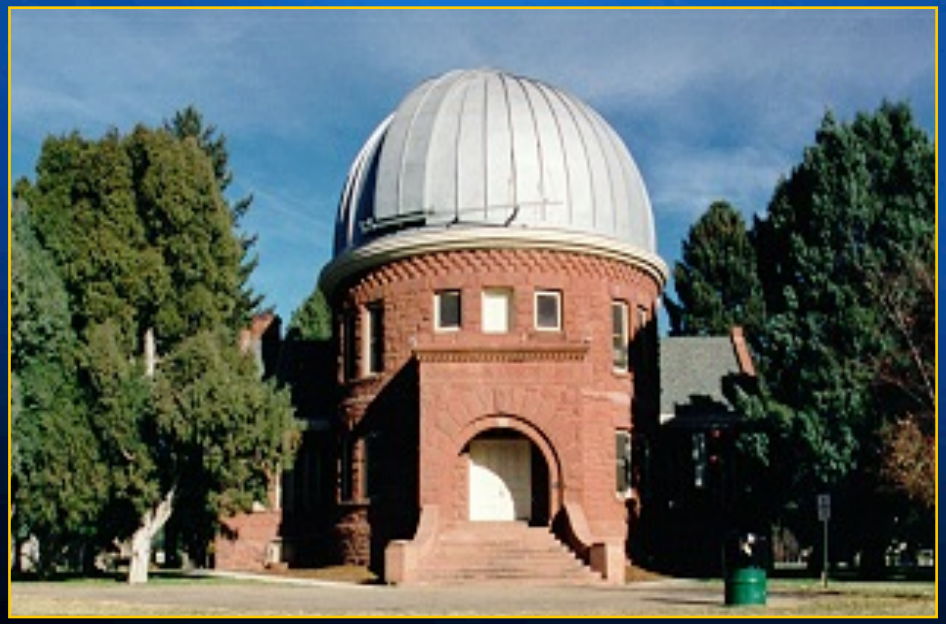




Zoldners, Calibration and Use of Impact Test Hammer, ACI Journal, 54(2) 1957.

Rebound hardness applications

- General indication of material properties
- Locate deterioration
- Evaluate fire-damaged masonry, concrete
- Qualify pointing mortar for repair
  - Quality assurance following repointing
- Evaluate mortar in new construction



Chamberlin Observatory, Denver

Sounding

- Near-surface delaminations and spalls

Pachometer

- Used for locating embedded metals
  - Pulse induction method
  - Detects any conductive metal

www.elcometer.com

Metal detection

- Reinforcement
- Anchors
- Flashing
- Conduit
- Pipes
- Electrical

Photo by Zach Rice

Pachometer - limitations

- Most devices made for evaluating concrete
  - Max. detection depth 15 to 20 cm
- Measurements affected by:
  - Near-surface or adjacent metals
  - Variations in base material
  - Electromagnetic fields
  - Large metal watches

Pulse Velocity

- Stress wave transmission
  - Ultrasonic
  - Sonic (mechanical pulse)
- Parameters of interest
  - Arrival time: velocity
  - Amplitude: attenuation
  - Frequency: attenuation, reflections from subsurface anomalies

Pulse Velocity Testing

Poisson, 1848

- Theory of compression waves in solids:

$$V^2 = \frac{E_d}{\rho} \frac{(1-\nu)}{(1+\nu)(1-2\nu)}$$

E_d = dynamic modulus

ρ = density

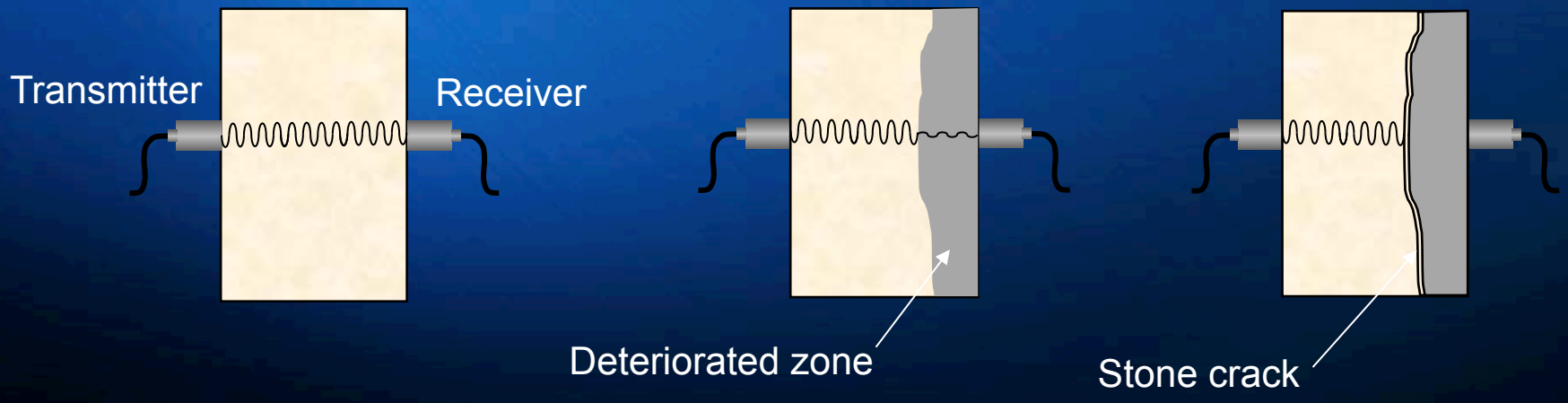
ν = Poisson's ratio

➔An *indicator* of strength, quality

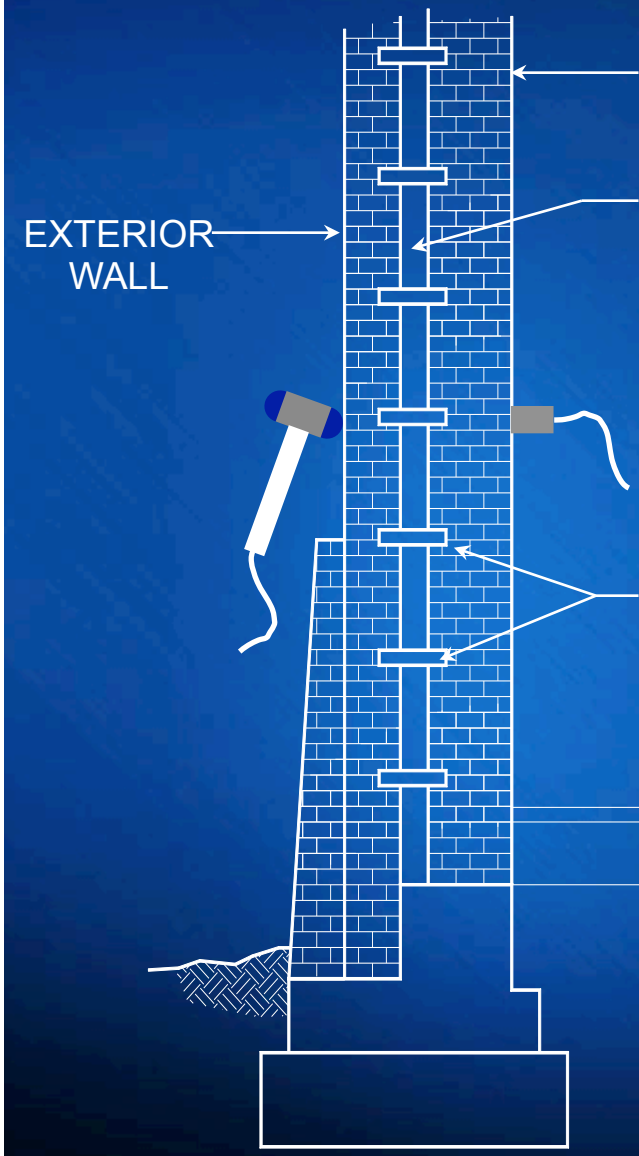
- Aerojet Corporation, 1967
  - Investigation of sonic testing of masonry walls

Pulse Velocity Testing

- Wave transmission affected by:
  - Dynamic modulus
  - Density
  - Interfaces between materials



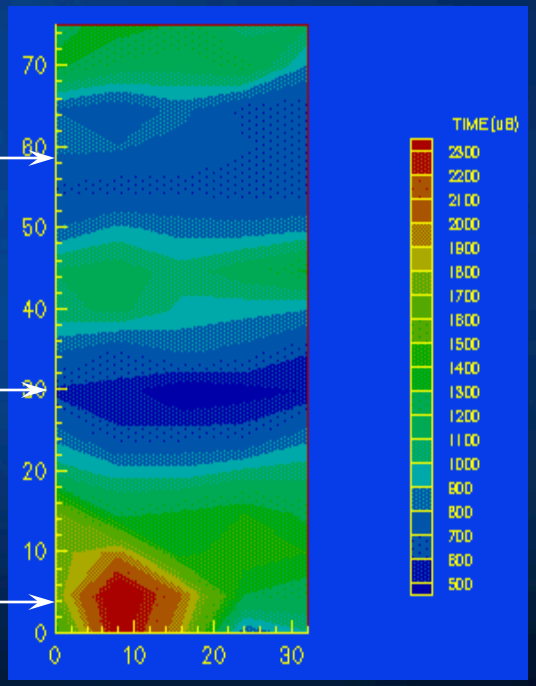
Header Courses



- Where are they?
- Broken or intact?

Tie Course

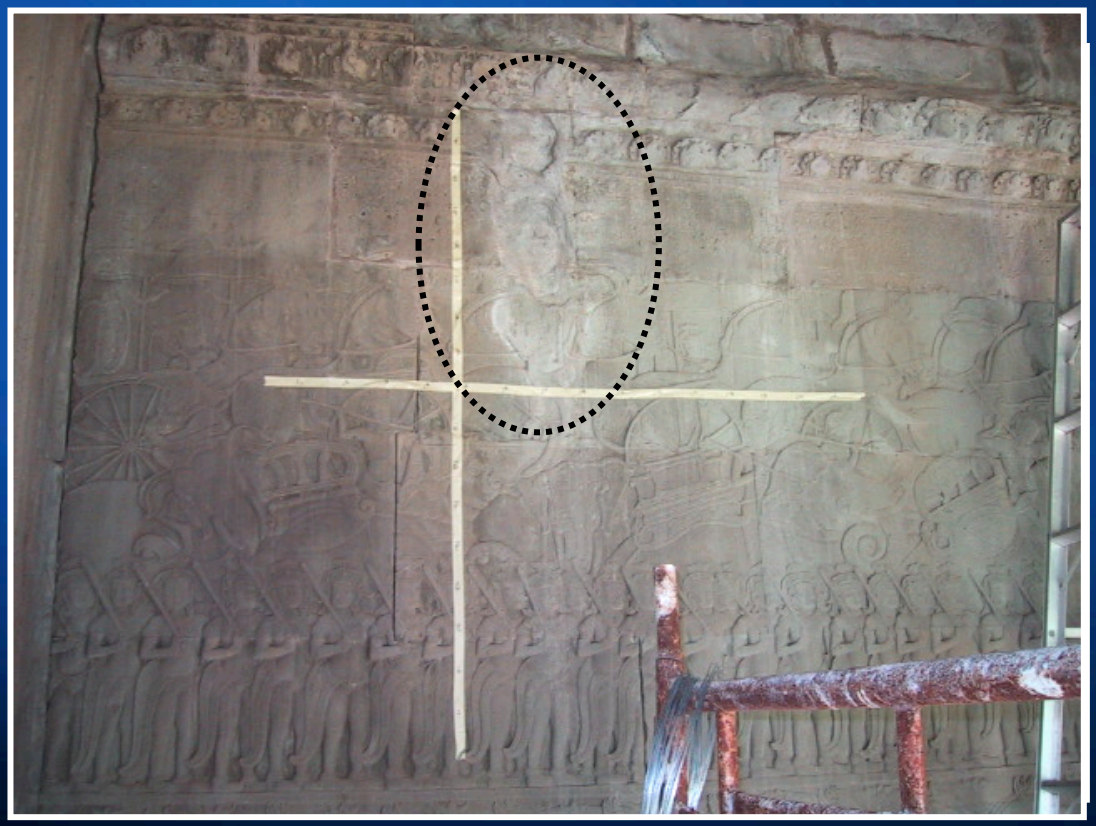
Void



Mechanical Pulse Velocity

Pulse Velocity Applications

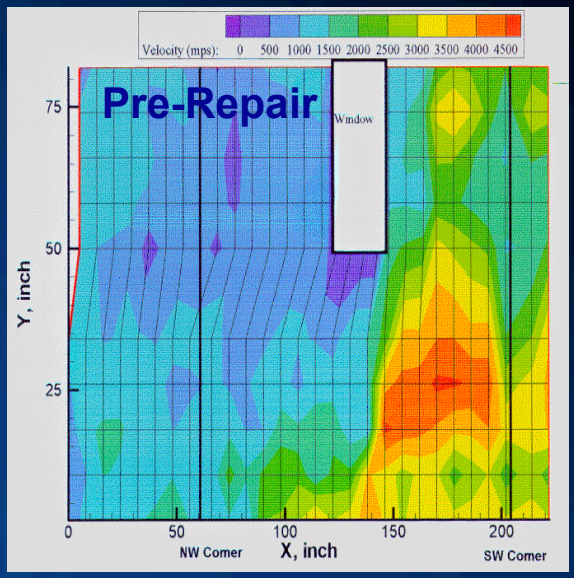
- Material uniformity

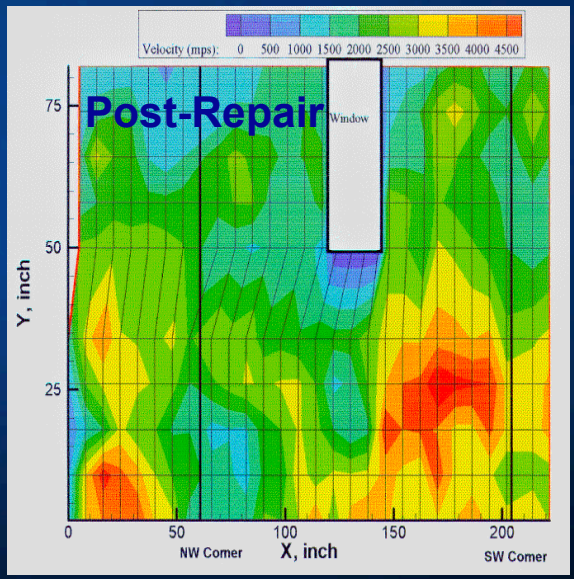


Churning of the Sea of Milk Gallery
Angkor Wat, Cambodia

Pulse Velocity Testing

- Capabilities
  - Internal construction
  - Locate internal anomalies: voids, cracks
  - Quality control: repairs
- Limitations
  - Two-sided access required
  - Point-by-point measurements
  - Rough surface: coupling req'd





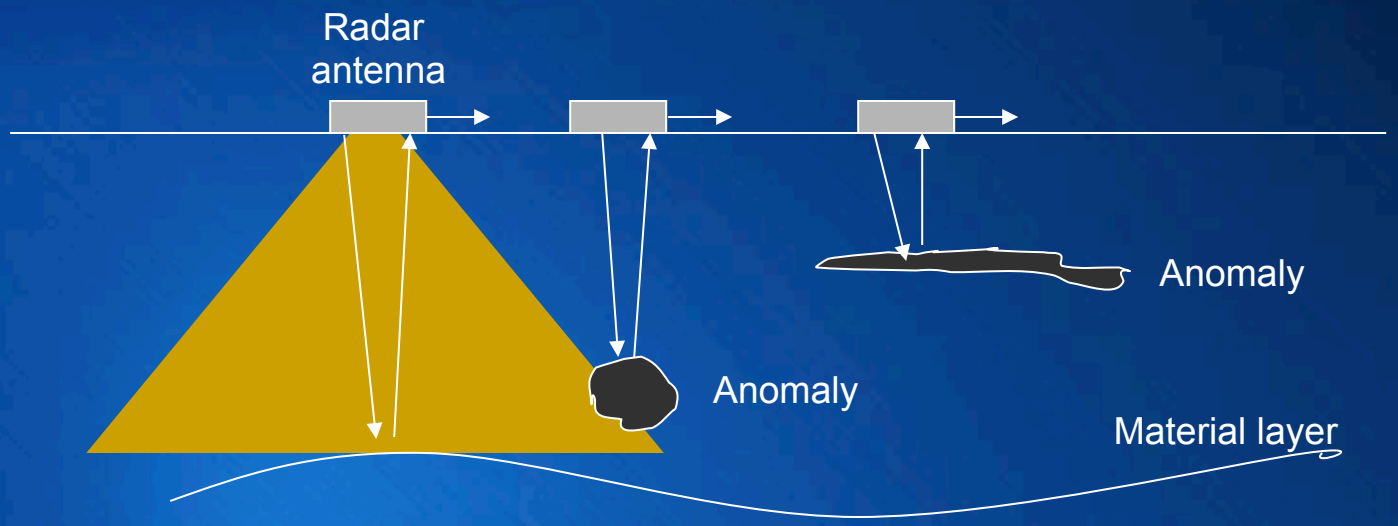
Microwave radar

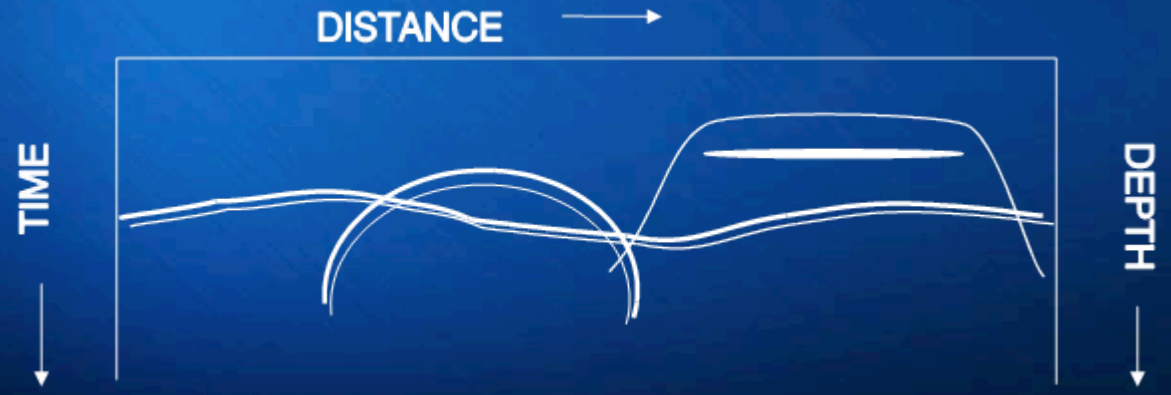
Ground penetrating radar: GPR

Surface penetrating radar: SPR

- Sensitive to dielectric variations
  - Voids
  - Cracks
  - Embedded metals
  - Moisture
  - Salts

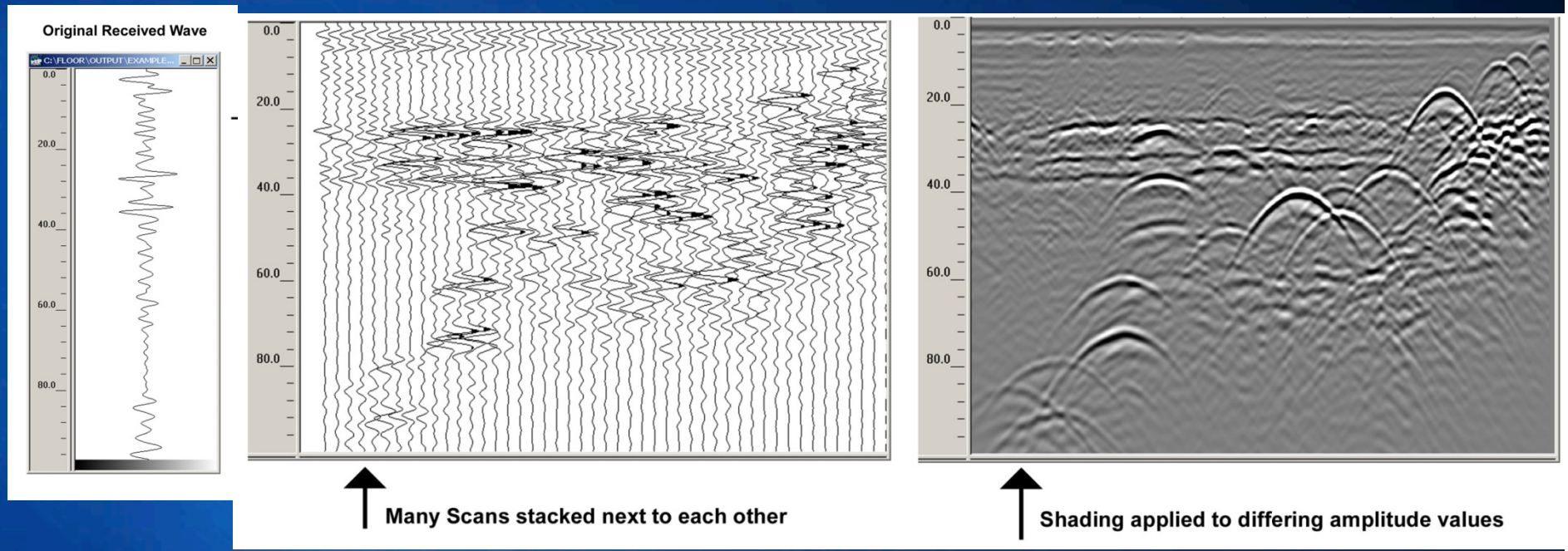
Radar data acquisition





Source: GSSI

From Line Scans to 2d Images



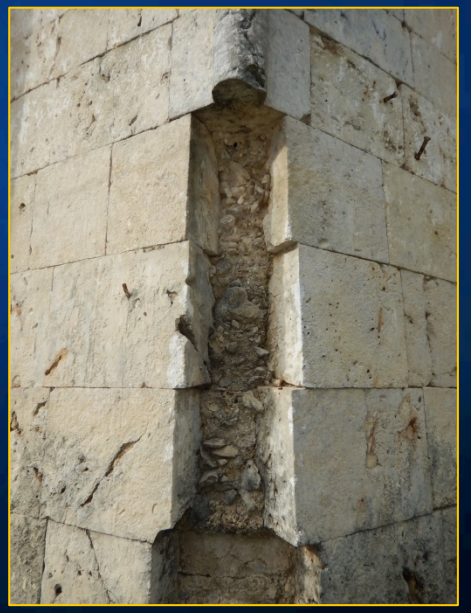
Source: GSSI

Microwave radar characteristics

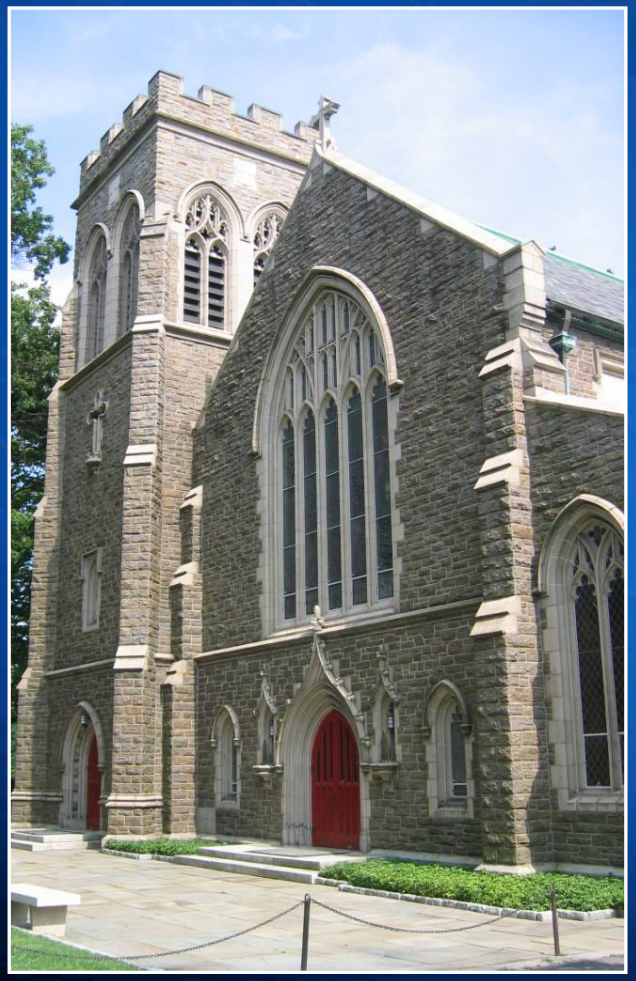
- Average radiated power
  - Transmitted power ~ 1% of cell phone
- Practical limits
  - 18 to 30 inches in masonry/concrete
  - 30 feet to detect objects in the earth
  - 100 feet to detect water table, bedrock in earth
  - 1000 feet in ice to detect bedrock

Applications in Historic Structures

- Locating below-ground features
  - Gravesites, pipes, disturbed earth
- Determining thickness of floors or walls
- Locating bond stones and header courses
- Identifying voids or rubble fill within walls
- Imaging metal inclusions in concrete and masonry
- Mapping moisture content in materials
- Quality assurance in localized repairs



SPR: as-built information



Christ Church, Greenwich, CT

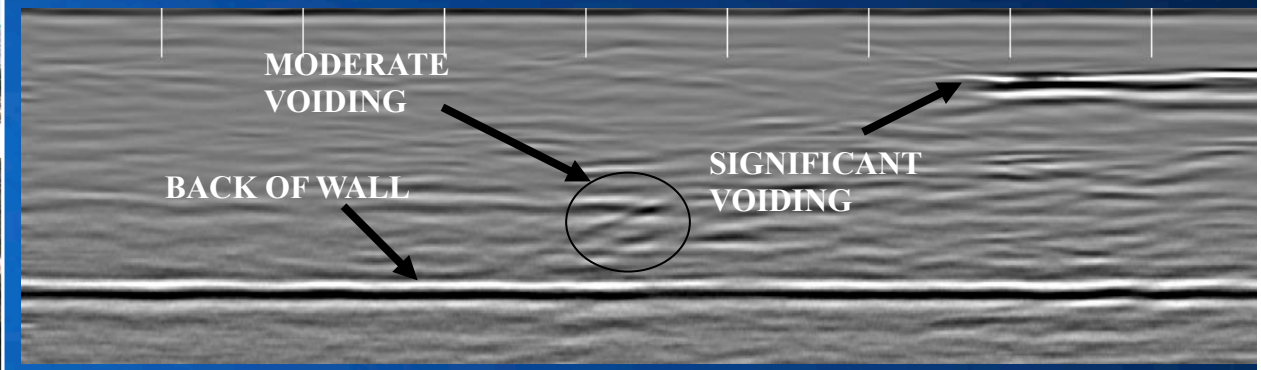
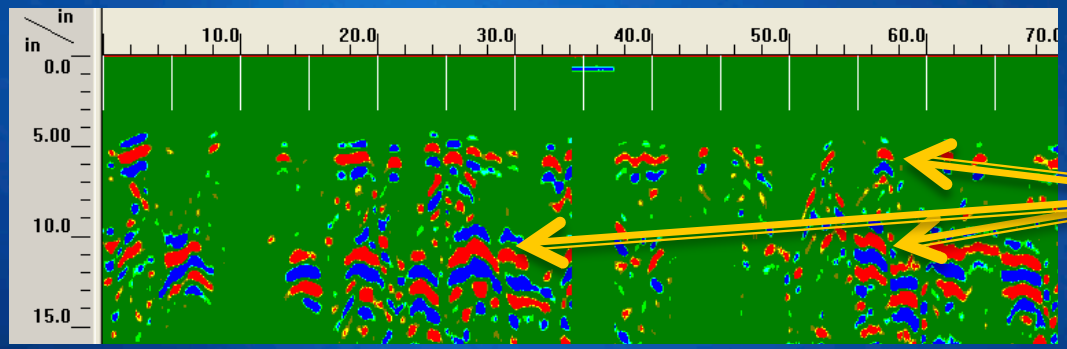


Figure 3 – GPR scan 030 from location #7

SPR: quality assurance

- How do you make sure a wall is injected properly?
  - Microwave radar
  - Borescope



Radar Scan
Pre-injection

Many void
collar joints

Post-
injection

SPR Evaluation

Beware of:

- Large metal inclusions
- Moisture variations
- Salts

Moisture Meter

Use complementary methods:

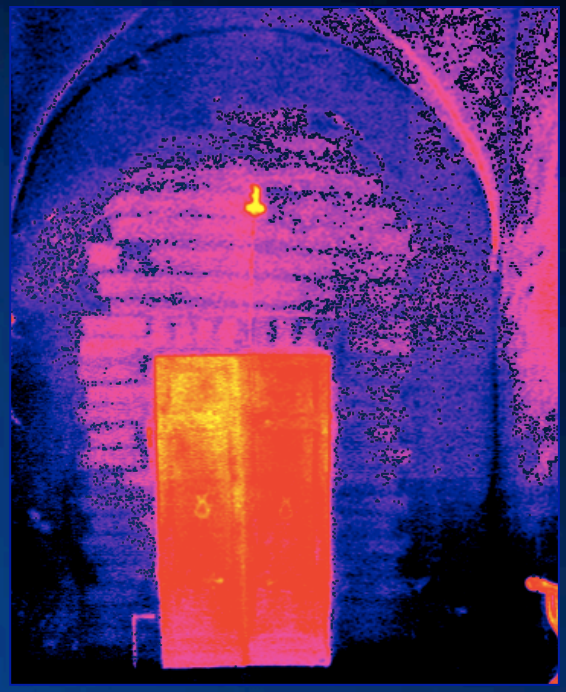
- Metal detectors
- Moisture meters
- Borescope examination

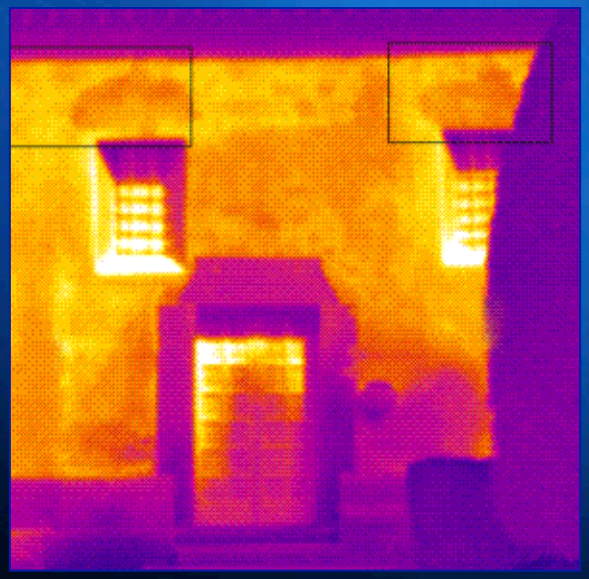
Infrared Thermography

- Measures infrared radiation emission from surfaces
- Surface temperature: 0.1° C resolution
- Variations in
  - Material density
  - Construction
  - Moisture

Infrared Thermography

- Difference in heat transfer characteristics
  - Voids
  - Material variations

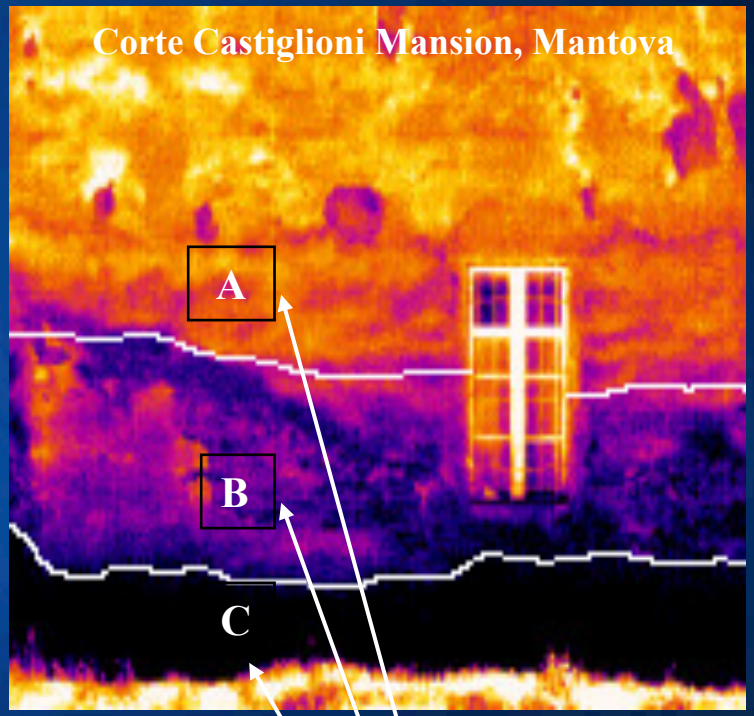




Jonathan Spodek, Ball State University

Infrared Thermography

- Moisture content variations



Jonathan Spodek, Ball State University

Borescope Evaluation

- Use for *verification/proofing* of conditions discovered using NDE methods

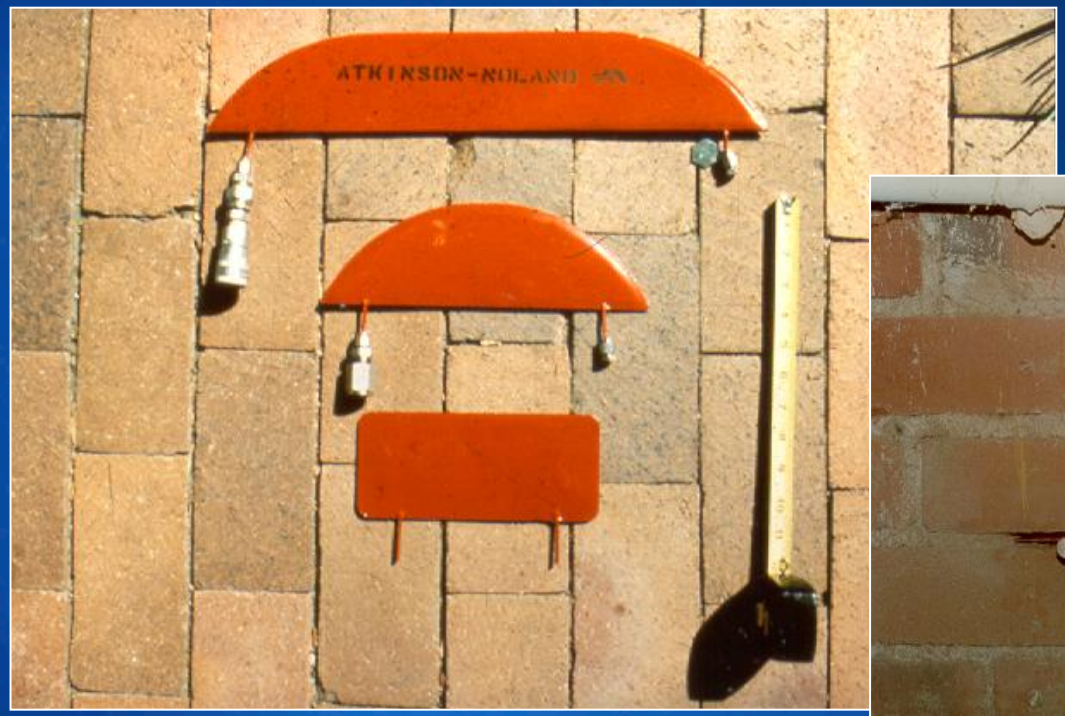
Anchor condition

Voids

In Situ Tests

- Engineering properties
  - Existing stress: ASTM C1196
  - Compressive strength: ASTM C1197
  - Shear strength: ASTM C1531
  - Anchor capacity: ASTM E488

Flatjack Testing

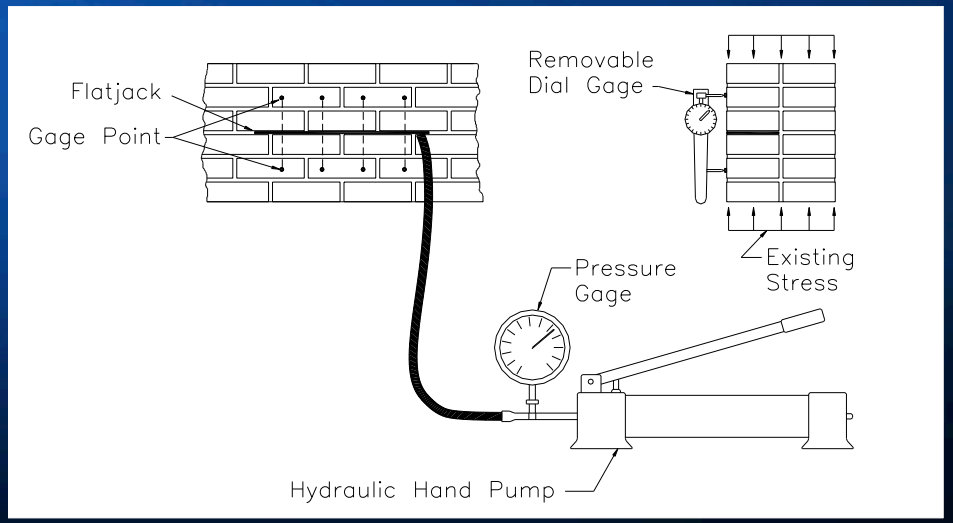


Flatjacks: thin hydraulic pressure cell

In Situ Stress Test

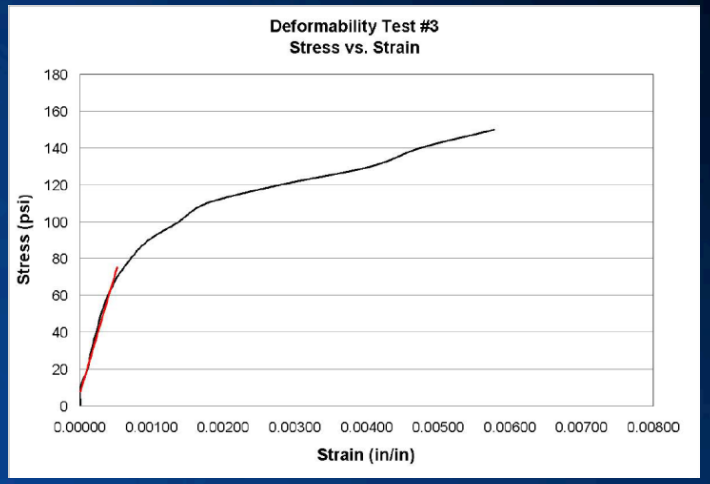
Direct measure of compression stress at test location

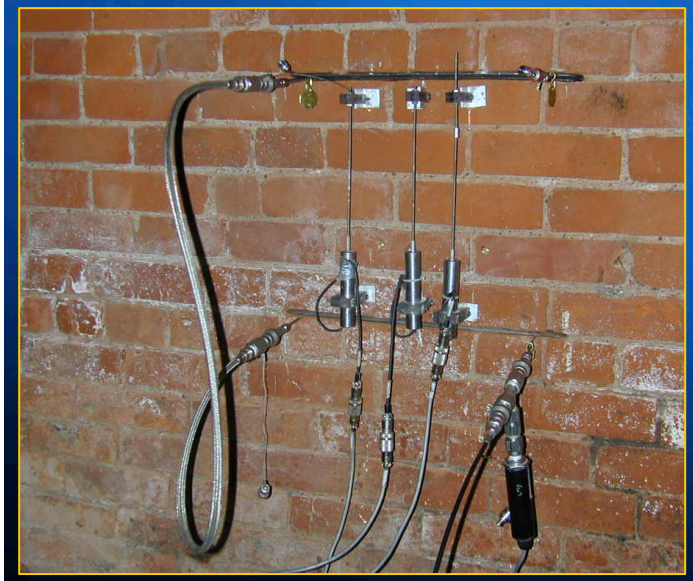
- Measure dead load stress
- Stress distribution in arch, vault
- Stress gradient across wall: bending moment
- Long term monitoring



In Situ Deformability ASTM C1197

Determine stiffness, strength, in place





In Situ Shear Test

- ASTM C1531,
  Standard Test Methods for Determination of Masonry Mortar Joint Shear Strength Index

- International Existing Building Code
  - IEBC Section A106.3.3.1
  - Data analysis and use

Laboratory Analysis

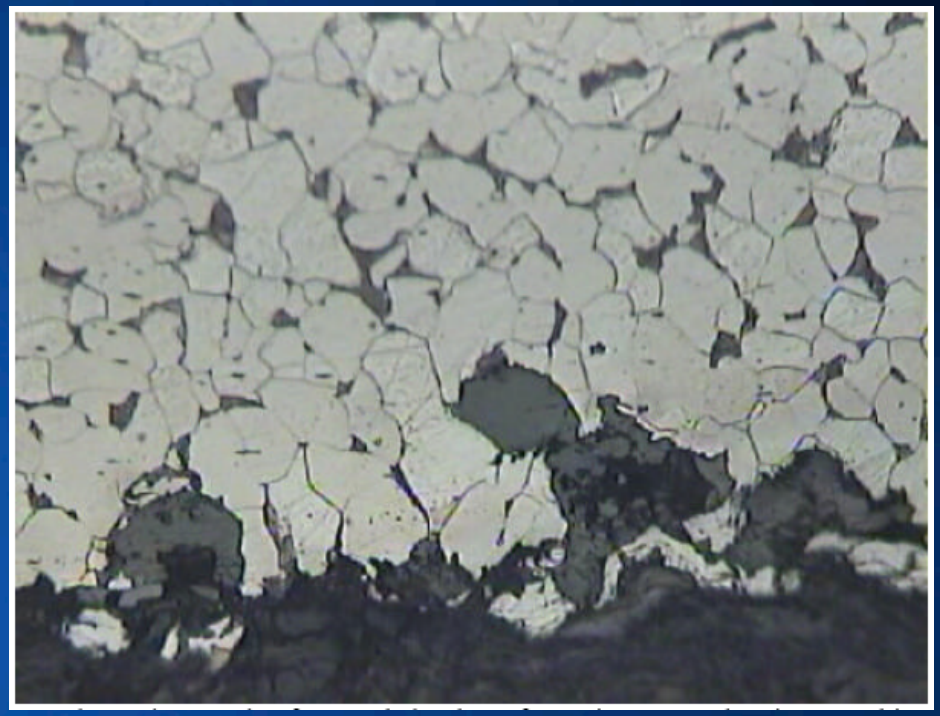
- Why?
- Where to sample?
  - Original, deteriorated, typical
- How much material?
- Budget?

Laboratory Analysis

- Material analysis
  - Binocular microscope
  - Scanning electron microscope
  - X-ray diffraction (minerals)
  - FTIR (elemental composition)
  - Chemical analysis

Metal Identification

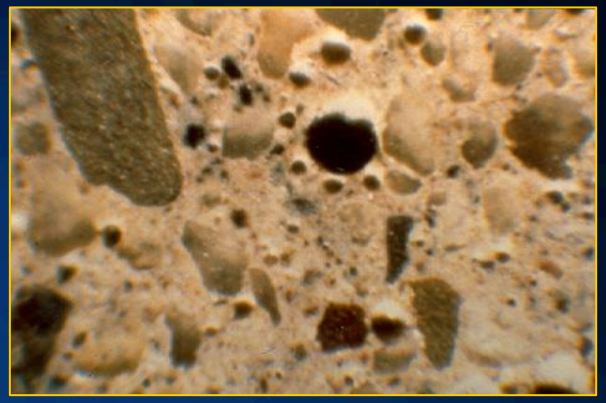
- Tension strength
  - ASTM A370
- Chemical makeup
  - Optical spectroscopy
- Metallography
  - Microscopic examination



Photomicrograph of Corroded Edge: Uniform and Pitting Corrosion. (Original 250X, 2% Nitol Etch)

Mortar: Petrographic and Chemical Analysis

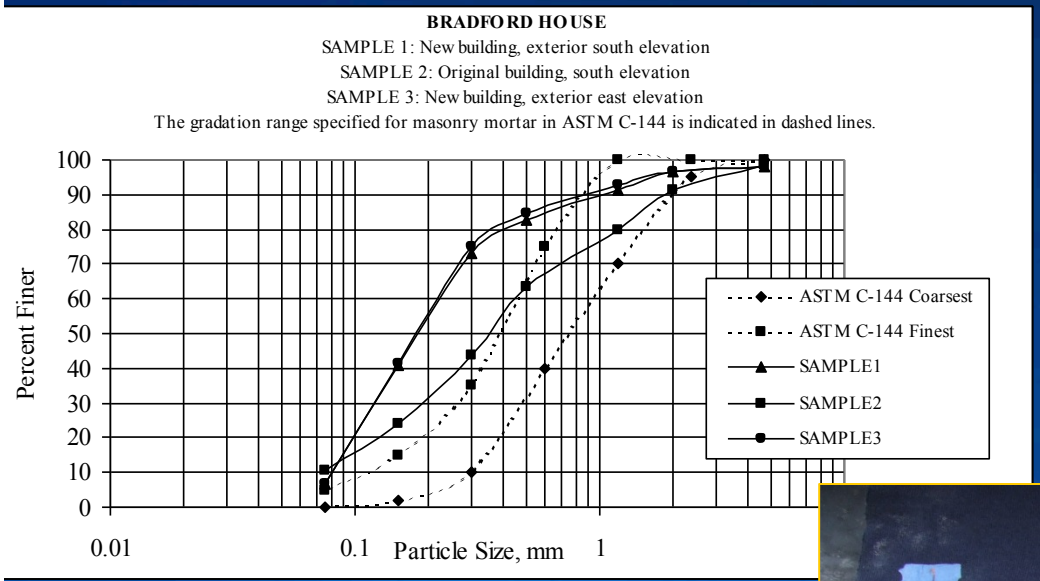
- Mix Proportions
- Lime, Cement Content
- Air Content
- Aggregate Type
- Binder composition
- Image analysis: deterioration mechanism

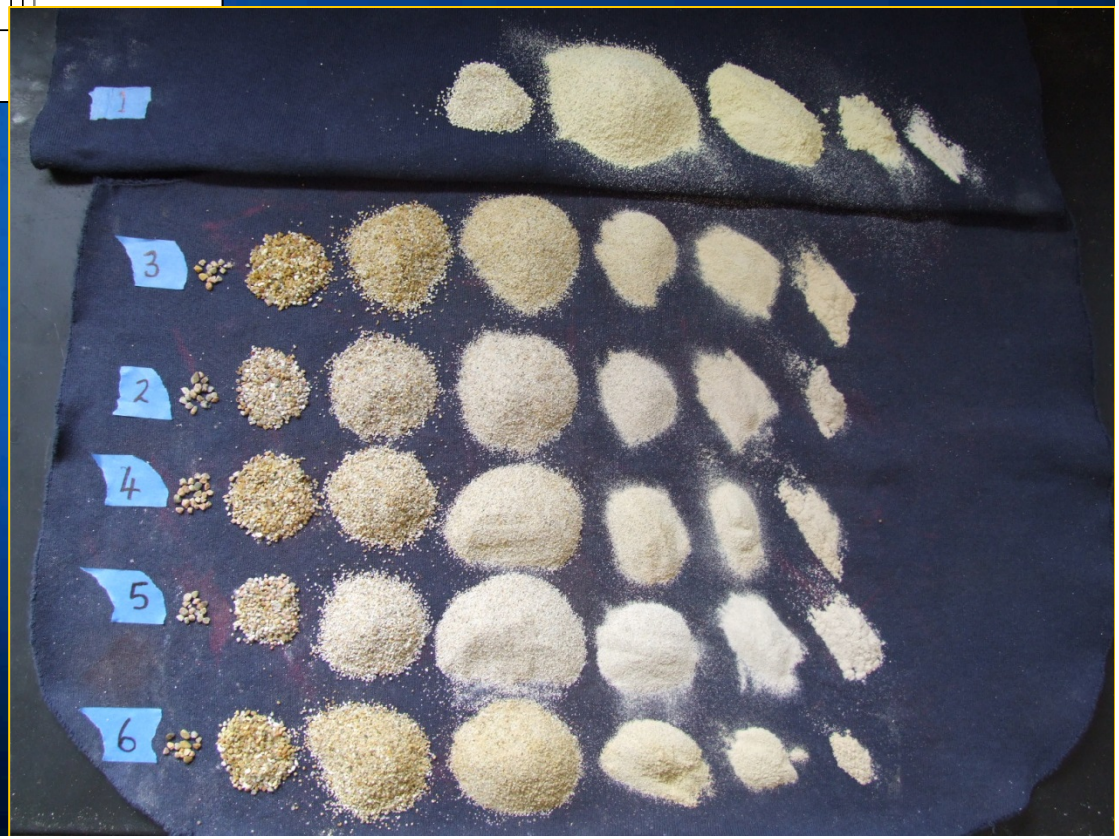


ASTM C856, *Standard* Practice for *Petrographic* Examination of Hardened *Concrete*
ASTM C1324, *Test Method for Examination and Analysis of Hardened Masonry Mortar*

Mortar Analysis

- Aggregate type, gradation





Planning an Investigation
How best to employ NDE

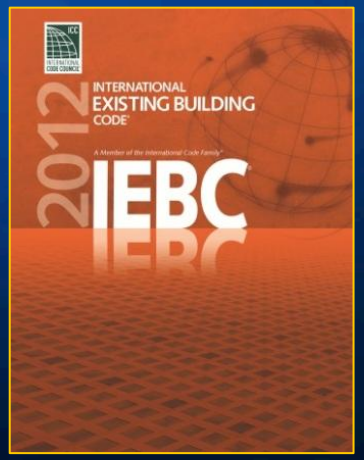
- What information do you need?
  - As-built conditions
  - Damage mapping
  - Material properties
- Assemble *a priori* information
  - Original documents
  - Photographs
  - Prior reports

Planning an investigation

- How many tests?
- Confidence limits, expected accuracy
  - New construction: 3 specimens = 1 test
  - How variable is the construction/condition?
  - Different construction eras
  - Different materials
  - Deterioration/damage

International Existing Building Code

ASCE 41: Seismic Evaluation and Rehabilitation of Existing Buildings



Some final thoughts...
The client should consider:

- Experience required to interpret test data
- Many NDE methods are affected by secondary phenomena (moisture, salts, boundary conditions)
- Be suspicious of the single-method approach
- Verify findings with other methods
- Will the repairs be expensive?
  - Verify conditions visually first

More Information

- APT: Association for Preservation Technology
  - Preservation Engineering Technical Committee
  - Documentation Technical Committee
  - Preservation Briefs: NDE for wood, masonry
- TMS: The Masonry Society
  - Existing Masonry Committee

www.apti.org

www.masonrysociety.org

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